Migration and Imaging With the Optimal Aperture.

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The theory of seismic migration based on Kirchhoff solution of the scalar wave equation is strictly applicable for only 3-D acquisition geometry. The fact, that it proved to be useful also in 2-D practice, has had significant influence on the state of the art in reflection seismology and made progression to 3-D imaging simpler. On the other hand, 2-D migration experience is not totally acceptable in 3-D case. There are at least two reasons for that. (1) Diffractions by aperture edges (edge effects) are much stronger in 3-D migration (Zavalishin 1997, 1998). (2) A point diffractor ceases to be an adaptable model of a secondary wave source because in edition to other shortages it does not reproduce dip and azimuth dependence of reflections.

Although it is known that data from a relatively small portion of an observation surface are responsible for restoration of an extrapolated signal, correct solution of the backward wave-extrapolation problem (migration) is only possible using data from an infinite observation surface. The limitation of a surface by an aperture of any shape and size causes appearance of edge diffractions in extrapolated wave field. Strictly speaking, it excludes possibility of exact extrapolation. Anticipated objections to this remark may come either from geometrical optics' considerations that do not take aperture diffractions into account or from high frequency approximations that treat them inaccurately in seismic band. Depending on aperture size, the diffraction noise contaminates the signal being extrapolated itself or/and neighbouring ones on shallower depths. It should be made clear that tapering or whatever else unable to solve this problem cleverly. Even highly attenuated diffractions, accompanying a strong signal, may seriously pollute its weaker neighbours. On the other hand, tapering attenuates diffractions by dispersing them over a longer interval, thus polluting data in its own way. This may mislead fine analysis of migrated data. Tapering also substantially increases calculations.

In a common case the aperture diffraction leaves no possibility for exact restoration of migrated signals. Taken for granted, it leads to conclusion that instead of suppressing diffractions it's better to try to make them allies the way it's being done in optics. This goal can be achieved, if inevitable distortion of the signal results in its amplification due to constructive interference. Aperture diffractions and migrated signal constructively interfere in the Fraunhofer zone where difference between their arrivals is less than one-half the period of the signal. It means that aperture dimensions should not exceed dimensions of the first Fresnel zone. One can come to this obvious conclusion (Gardner et al. 1974) without considering the aperture diffractions at all. Their consideration helps to understand why bigger apertures produce much noisier images, especially in 3-D.

To illustrate what was said, the results of migration from variety of circular apertures with different weight functions ($\Delta x=25m$) to the flat reflector's depth at $z=1.5$ *km* ($v=2$ *km/s*) are shown in Fig. 1. To avoid spatial sampling effects, the exact analytic solution of the wave extrapolation problem was used (Zavalishin 1989). Radii of apertures $A_i = 2\sqrt{vzT_i}$ correspond to four specific values of time delay T_i between reflection and migration hyperbolae at the aperture edge. These four values are: T_0 - a quarter of ap-parent period of the signal (A_0=.25 *km*), T_1 - one-half of the apparent period of the signal

(A_1=.35 km), T_2 - one-half of the signal duration (A_2=.5 km), T_3=.04 sec - the signal duration (A_3=.7 km). Note, that T_i also defines time difference between arrivals of the signal and diffraction noise in extrapolated (migrated) field at a reflector' depth. The bigger aperture *A=1 km* serves the purpose to illustrate complete separation (*T=.083 sec*) of the ideally reconstructed signal and diffraction noise.

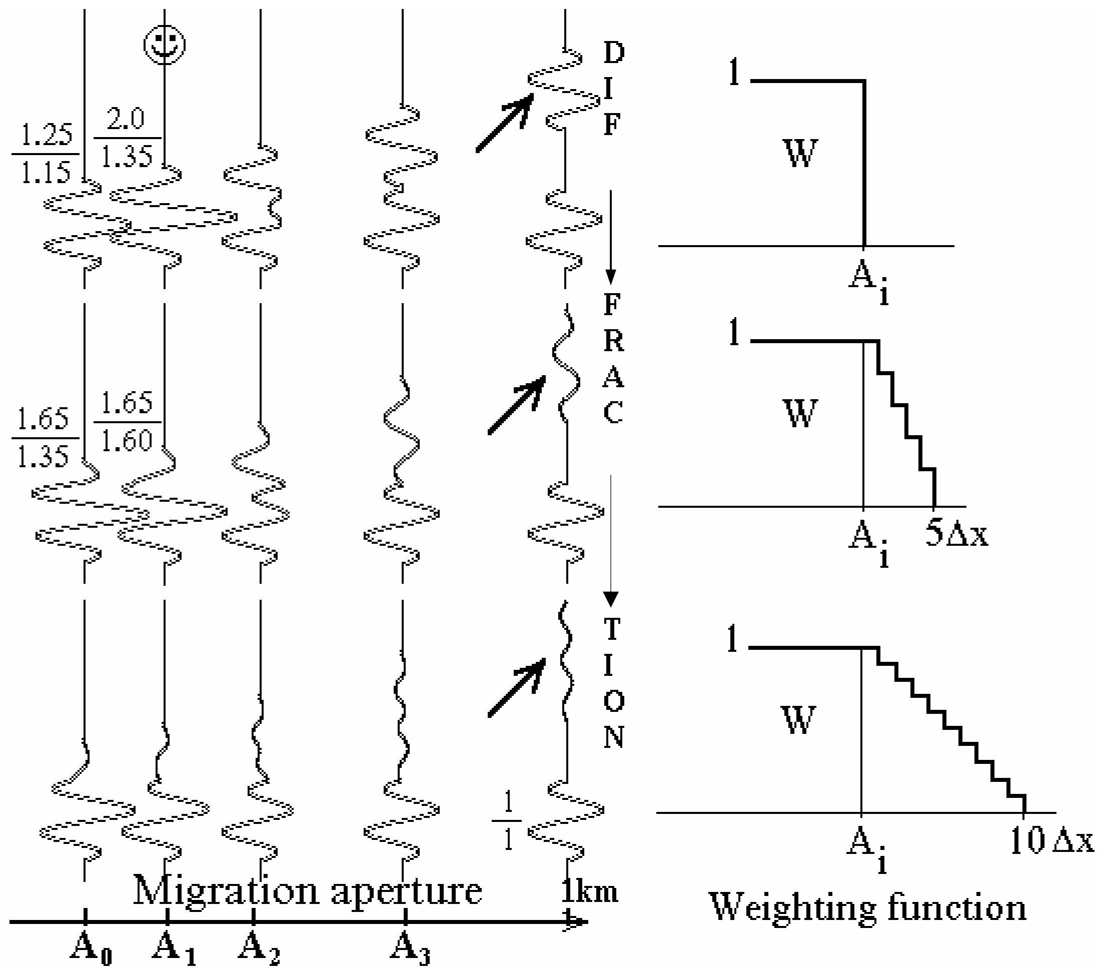

Fig. 1

Only migration with two smaller apertures provides appropriate results. For their quantitative distinction relative amplitude and duration of migrated wavelets are shown as fractions. Note also, that these wavelets look like the signal derivative. It means that their increased duration in comparison with the signal's duration not necessarily causes loss of high frequencies. The experiment leads to the conclusion that an aperture for 3-D migration and imaging should not exceed dimensions of the first Fresnel zone.

Migration of a reflected wave is possible if an aperture contains the stationary point. The stationary point is the point of tangency of the reflection and the stacking hyperbola. Optimal migration attainable with a small aperture assumes that the stationary point is placed in the centre. Fulfilling this condition in the existing practice takes much efforts and computations. Here is the alternative approach to the solution of the migration problem free from any headache on positioning of apertures.

With the stationary point at the centre of an aperture, efficiency of migration depends only on the time delay between reflection and migration hyperbolae at the aperture edge. For apertures not exceeding dimensions of the first Fresnel zone the time difference between stacking *D(x)* and reflection *R(x)* curves (Fig. 2) is convenient to evaluate after expansion of radicals

$$D(x) - R(x) = \frac{t_0}{2} + \sqrt{\frac{t_0^2}{4} + \frac{x^2}{v^2}} - \sqrt{t_0^2 + \frac{x^2}{v^2}} \approx \frac{\boldsymbol{x^2}}{\boldsymbol{2v^2 t_0}} - \frac{7x^4}{8v^4 t_0^3} + \frac{31x^6}{16v^6 t_0^5} + \dots \quad . \qquad (1)$$

The first term of this series is equal to the one in the normal moveout expansion

$$\Delta t_{NMO} = R(x) - t_0 = \sqrt{t_0^2 + \frac{x^2}{v^2}} - t_0 \approx \frac{\boldsymbol{x^2}}{\boldsymbol{2v^2 t_0}} - \frac{x^4}{8v^4 t_0^3} + \frac{x^6}{16v^6 t_0^5} + \dots \quad . \qquad (2)$$

This equality means that stacking of the reflection *R(x)* along *D(x)* to migrate data into point *d* of the reflector is equivalent to stacking it along the tangent line $t_0 = const$ (Fig. 2). In this particular case it means that simple summation of common shot data fulfils the purpose.

To migrate data into point *d* (Fig 3,a) the aperture should be centered at the stationary point *s*. As Fresnel zones get elliptical here with longer axis increased by the factor $1/\cos\alpha$, the same should be done with the aperture length. To make sure that migration in this particular case has much in common with the previous one, consider new co-ordinate system x_1, z_1 with the origin at *s* and axes turned by α so that z_1 passes through *d* and the image source. As the time-distance curves are symmetrical in the new co-ordinate system (Fig. 3,b), this case is similar to the previous one (Fig.2). It means that stacking the reflection $R(x_1)$ along $D(x_1)$ is equivalent to stacking it along the tangent $P(x_1)$. In normal *(x,z)* co-ordinates it justifies stacking data along tangent $P(x)=dt/dx=(\sin\alpha)/v$ (Fig. 3,a). The common case of a dipping reflector considered the same way leads to the similar conclusion.

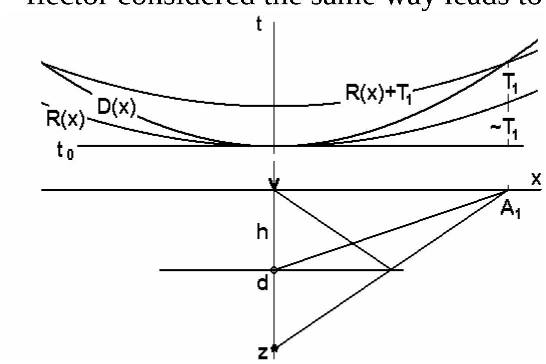

Fig. 2

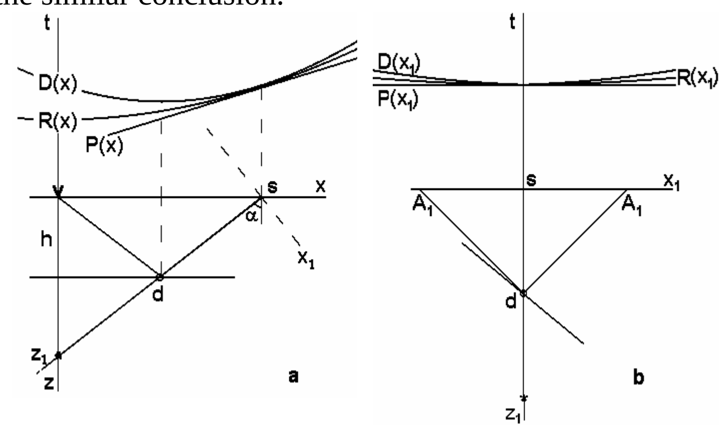

Fig. 3

There is nothing strange in it because any wave field can be decomposed into a set of either spherical or plane waves. The former associates with modelling a reflector by continuity of point sources, the later - by continuity of tangent planes. Selection of either of them is a matter of convenience. In early days of migration its apparent likeness to holography inspired selection of the point scatterer as an appropriate model for a secondary source. It suggested deceptive convenience not to think of Snell's law. Now it's getting clear that the choice was not that good.

It is true that seismic data and a hologram are similar in the sense that both contain "whole" information on an object(Robinson 1998). But structure and value of this information are very different. In holography it consists of scattered waves bearing information on every *real irregularity* on the object's surface. For this reason any portion of a hologram participates in imaging constructively. Specular reflections create problems -- too dark speckles on a hologram and corresponding gleams on an image. As a result one can get the perfect holographic image from a painting, but not from its glossy photocopy. Note, that a photocopy *may be thought* consisting of point diffractors the same way we think of a geological boundary. This analogy leads to the conclusion that by following holographic procedures with data represented primarily by specular reflections (French 1976) we image gleams (not scatterers). They are highly undesirable in holography, but proved to be useful in seismology as images of half-transparent reflectors.

Understanding of what we really imaging: scatterers or reflectors may help to do it in a more efficient way.

Reflected data satisfy Snell's law. For this reason wave information about a given reflecting point is concentrated in the limited area (of an order of Fresnel zone) around the stationary point, rather than spread out through whole the observation surface as the point diffractor model predicts. How to use such information for imaging has been known since 1930's (Rieber 1936). Recent developments in theory and technology make the idea only more sound.

The imaging problem may be formulated in this way. (1) Extrapolate every signal to the corresponding (stationary) reflection point. (2) Distribute it along the surface participated in its generation proportionally to contribution. (3) Combine (stack) results from all observation points. The second step, absent in the existing practice, is supposed to take into account that only a surface (not a point) emanates secondary waves (Zavalishin 1975, Knapp 1991, Bruhl et al. 1996). It should improve images because fragments from neighboring observation points overlap, and may ease the problem of acquisition footprints.

Essential element of the approach described bellow is that every observation point is the stationary point for variety of reflections and diffractions coming from unknown distances and directions. Plane wave decomposition of surrounding data helps to locate corresponding points of reflection and diffraction.

2-D extrapolation procedure consists of data decomposition into plane waves by slant-stacking along variety of straight lines $P(\alpha,t)$, and their migration with appropriate weights along corresponding rays. In addition, results of decomposition, represented in the form of F. Rieber sonogram (L. Riabinkin summogram), provide good conditions for automated evaluation of parameters t, p and *amplitude* of decomposed waves. Their analysis and utilization may result in discrimination (muting or weighting), relieving data from migration noise, and/or fast construction of the macro model.

Migration of 3-D data is convenient to start with plane wave decomposition along two directions preferably, but not necessarily, orthogonal. Two derivatives $p(x)$ and $p(y)$ are sufficient to define the tangent plane along which the patch of data need to be stacked and the ray along which the sum should be migrated to the reflecting point. When this point is known, the optimal aperture size and shape (the first Fresnel zone) are easy to define.

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